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THE ECONOMICAL USE OF DURALUMIN AS A SUBSTITUTE FOR STEEL IN COMPRESSION

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THE ECONOMICAL USE OF DURALUMIN AS A SUBSTITUTE FOR STEEL IN COMPRESSION.

GENERAL DISCUSSION OF PROBLEM.

Duralumin can not be intelligently substituted for steel without some knowledge of the variation in the weight ratios for equal strength with changes of load, length, l/ρ, and end fixity. To enable the designer to choose readily between duralumin and steel for the lightest weight, this report has been produced embodying a study of weight ratios for common loads, lengths, and fixities. From the curves herein contained the designer may quickly choose between duralumin and steel if there has been obtained some preliminary knowledge of the load, length, or approximate size of the structure in question.

A study of curves of allowable compressive strengths will show that the proportionate loss in strength with increased values of l/ρ is not the same for all materials. For example, steels having a yield point in compression higher than 90,000 pounds per square inch lose strength more rapidly than does duralumin having a yield point of 30,000 pounds per square inch. Tubes of equal strength of duralumin and steel, by reason of the difference in unit stresses, will be of different sizes and will have correspondingly different values of ρ.

These two variables, loss of column strength and variation in values of ρ must be taken into account when studying the variation of the weight ratios of struts or other compression members.

METHOD OF STUDY OF PROBLEM.

The only structural form considered in this report is the tube. In order to make the results more comparable, a ratio of diameter to thickness of 18.75 was adopted, and in all the computations theoretical sizes and section properties were used. Because of the necessity of using standard tubes in actual design, the ratios of diameter to thickness for comparative designs will not be constant, and consequently the weight ratios will vary slightly from those given in this report, not enough, however, to affect their validity for preliminary designs.

PRESENTATION OF RESULTS.

The results of this investigation are presented in two forms. The first (figures 1 and 2) consists of curves of weight ratios plotted against values of l/ρ for steel with a companion curve of values of l/ρ for duralumin plotted against values of l/ρ for steel.

To use the cuves in figure 1, the value of l/ρ for the steel member must be known. If it should happen that the available data is for duralumin, the curves in figure 2 will give the corresponding values for steel, and figure 1 may then be used to determine the relative weights of the two designs.

The second form is a series of curves of weight ratios plotted against load (figures 3, 4, 5). Two sets of curves for different lengths have been plotted for each steel specification, one for $C=1$, and a second $C=2$. These curves will afford a rapid method of comparing the relative weights of steel and duralumin designs if the loads and the lengths are known. For cases not covered by these curves recourse must be made to figures 1 and 2.

From the curves in figure 1 it will be seen that pin-ended steel struts having a yield point of 90,000 pounds per square inch with an l/ρ of less than 33 will be lighter than duralumin of equal strength, and that the advantage of the steel will extend up to higher values of l/ρ as the yield point of the steel is increased by special heat treatments. A comparison of the curves for $C=1$ and $C=2$ will show that the range of superiority of the steel will also be extended by increasing the end fixity.

EFFECT OF LIMITATION OF CENTER HEIGHT.

A third variable affecting the weight ratios is the limitation of center height of spars by the wing section. The sizes of the flange members are determined by the moment at the section and the center to center distance of the flanges. In an internally braced monoplane wing where the stress is all bending, the use of the larger duralumin tubes instead of the smaller steel tubes may cut down the center to center distance of the flanges sufficiently to increase the flange stress 8 to 10 per cent. The attendant increase in the weight of duralumin raises the curves of weight ratios by an amount depending upon the spar depth. For spar design a fixity of 2 is usually assumed so that the curves of weight ratio will always lie above that for $C=2$. A comparison of weights of steel and duralumin wing spars for the CO-3 is given in the appendix; the decrease in the center to center distance of the flanges is illustrated in figure 6.

The above conclusions are based upon an assumed value of 30,000 pounds per square inch as the yield point in compression for duralumin, a value sightly higher than 27,000 pounds per square inch allowed by the Air Service Specifications. The Air Service figure is conservative, and will probably be increased in the near future to 30,000 or even 35,000 pounds per square inch.

APPENDIX NO. 1.

COMPUTATIONS FOR CURVES IN FIGURES 1 TO 5.

The first step was to design a number of tubes 10 inches in length for loads varying from 500 pounds to 40,000 pounds. These tubes gave values of l/ρ varying from 14 to 112. The allowable stresses used were taken from the column curves based upon the combined Johnson and Euler curves as used by the Engineering Division of the Air Service. From these computations, figures 1 and 2 were plotted. Subsequently, the work was repeated for lengths of 20, 30, 40, and 50 inches from which figures 3, 4, and 5 were plotted. As the sizes could only be obtained by a series of approximations, the following formulas were used for the section properties:

$$(1)\ \frac{D}{t}=18.75.$$

$$(2)\ A=\frac{\text{Load}}{\text{allow. } f_c}=\pi Dt=\frac{\pi D^2}{18.75}.$$

$$(3)\ I=\frac{\pi D^3 t}{8}.$$

$$(4)\ \rho=\sqrt{\frac{I}{A}}=\sqrt{\frac{D^2}{8}}=\sqrt{.745A}.$$

The following shows the method of calculating and comparing results worked out for duralumin and 90,000 pounds per square inch steel when c=1.

Load.	Length.	Duralumin. Assumed F_c.	Duralumin. Area.	Duralumin. l/ρ.	Duralumin. Actual f_c.	Steel. Assumed F_c.	Steel. Area.	Steel. l/ρ.	Steel. Actual f_c.	K.
5,000	10	28,200	0.1772	27.5	28,200	76,000	0.0657	22.1	76,100	0.960

K=ratio of weights

$$=\frac{\text{unit weight of duralumin}}{\text{unit weight of steel}}\times\frac{\text{area of duralumin}}{\text{area of steel}}$$

$$=\frac{2.80}{7.85}\frac{A_D}{A_S}.$$

The value of 0.960 is plotted in figure 1 against the value of l/ρ=22.1 which is the value for the steel. In figure 2, l/ρ for the steel is plotted against l/ρ for the duralumin.

APPENDIX NO. 2.

COMPUTATIONS FOR CO–3 ROOT SECTION.

The reduction in center to center distance of spar flanges through the use of large duralumin tubes instead of steel tubes is well shown in figure 6. The design moments are for the root section of the first set of Gottingen wings designed for the CO–3. Below are given the design stresses and sizes:

GENERAL DATA.

Available center height........15.55 inches.
Moment (high incidence)......1,010,000 inch-pounds.
Moment (reversed flight)........493,000 inch-pounds.
Panel length....................24 inches.

90,000 lbs. steel.		30,000 lbs. duralumin.	K.
c. to c.	13.67 in.	12.15 in.	
Upper chord:			
Stress..............	−73,200#	−83,200#	
Size................	2″×5/32	4″×1/4	
Area...............	0.905	2.95	1.16
Lower chord:			
Stress..............	[1]+62,200#	−42,000#	
Size................	1¾″×1/8	3″×5/32	
Area...............	[1] 0.638	1.396	[1] 0.78

[1] It will be noted that the lower chord of the steel spar was limited by tension instead of by compression. Duralumin, by reason of a high tensile strength as compared with its compressive strength is able to give lighter weight. In this case the logical procedure would be the use of a steel compression flange, with a duralumin tension flange. This type of construction is being tried out in the wing spars of the CO–1, an airplane of the same type and weight as the CO–3. This superiority of duralumin over steel in tension does not disappear until steel stronger than 155,000 pounds in tension is used, so that it appears that for most members in which tension governs, duralumin will give the lighter design.

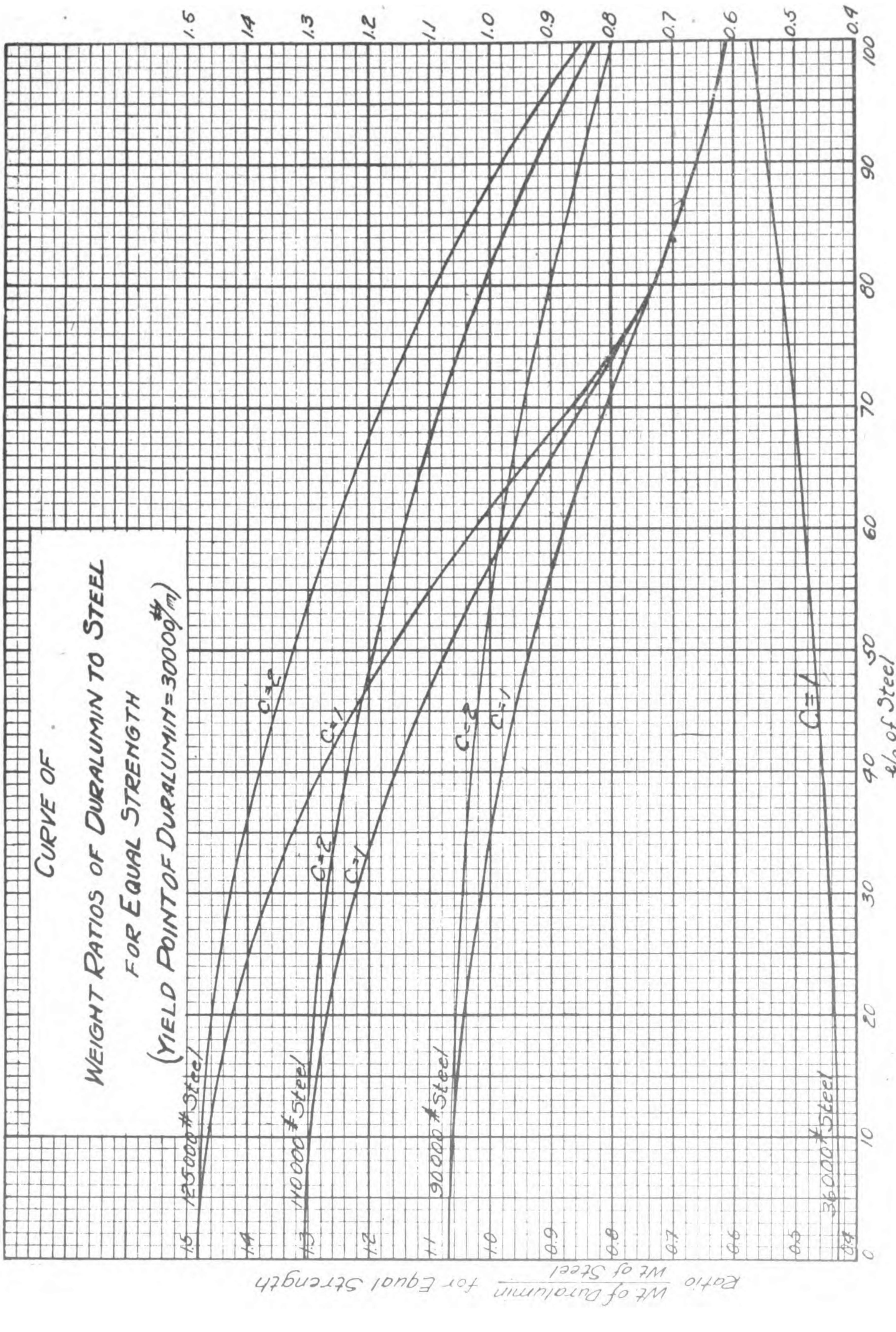
CURVE OF
WEIGHT RATIOS OF DURALUMIN TO STEEL
FOR EQUAL STRENGTH
(YIELD POINT OF DURALUMIN = 30000#/in)
125000# Steel
110000# Steel
90000# Steel
36000# Steel
l/ρ of Steel
Ratio Wt of Duralumin / Wt of Steel for Equal Strength

FIG. 1.

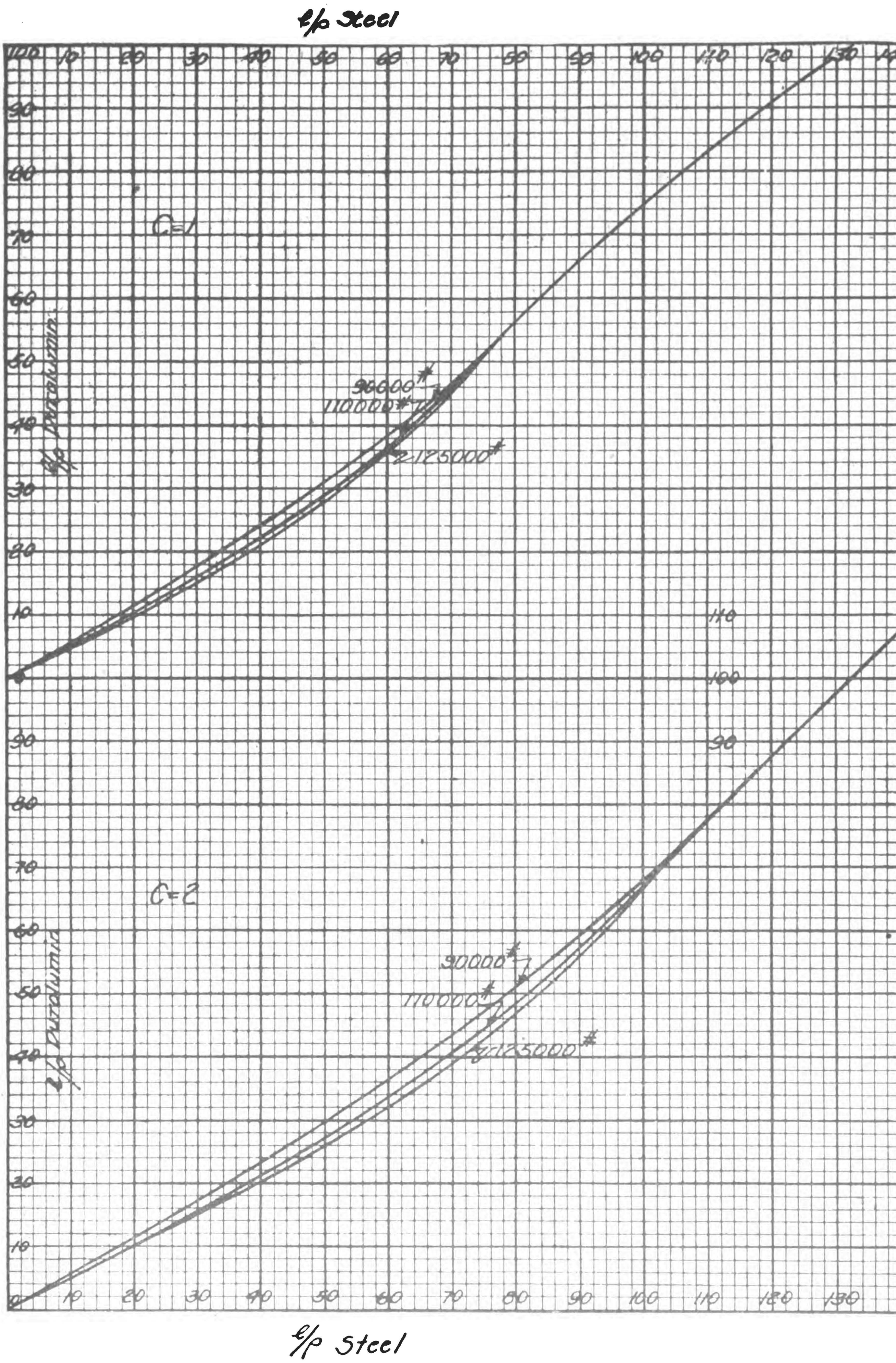
e/p Steel
C=1
90000#
110000#
125000#
e/p Duralumin
C=2
90000#
110000#
125000#
e/p Duralumin
e/p Steel

FIG. 2.

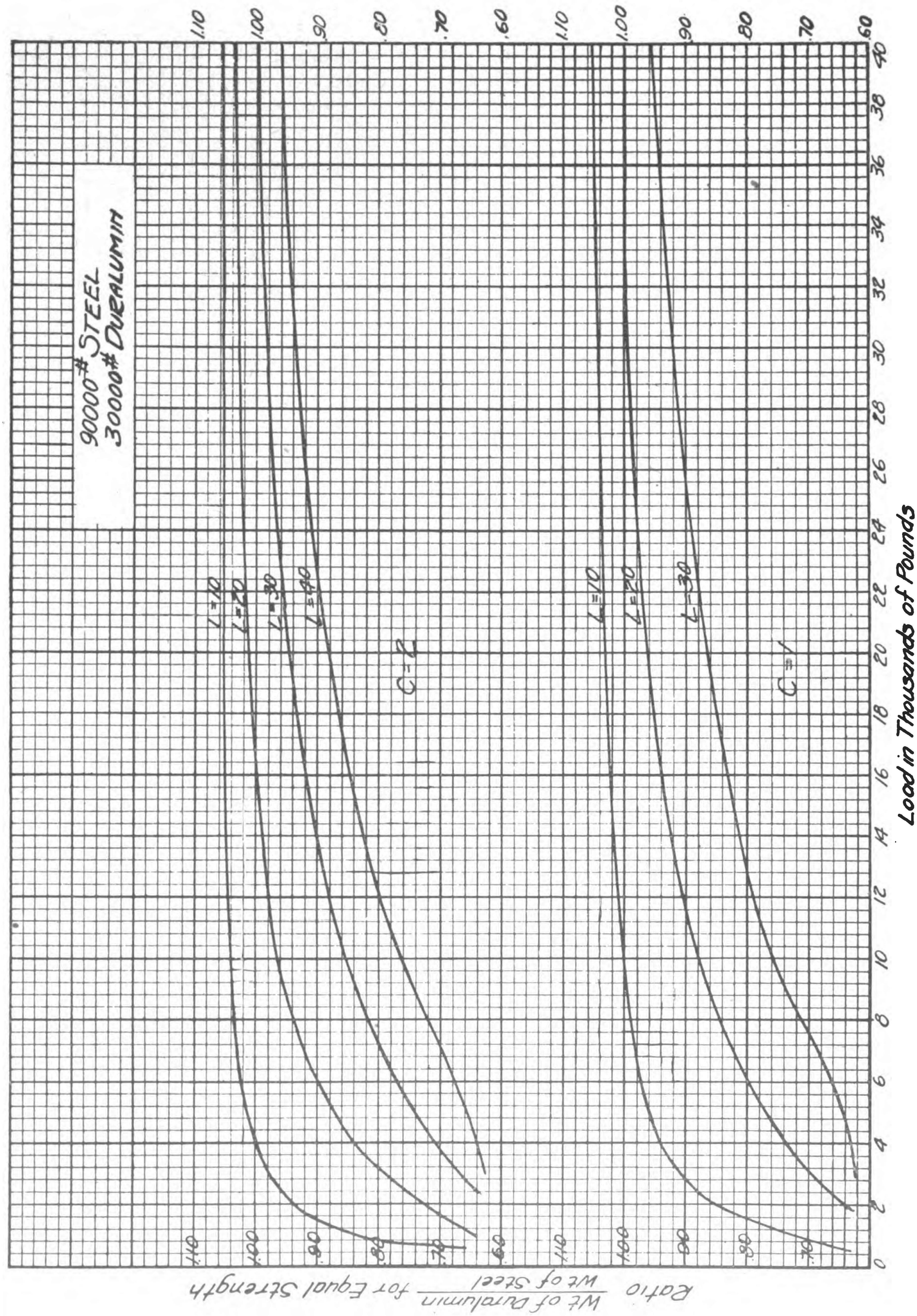
90000# STEEL
30000# DURALUMIN
L=10
L=20
L=30
L=40
C=2
C=1
Load in Thousands of Pounds
Ratio
Wt of Duralumin / Wt of Steel
for Equal Strength

FIG. 3.

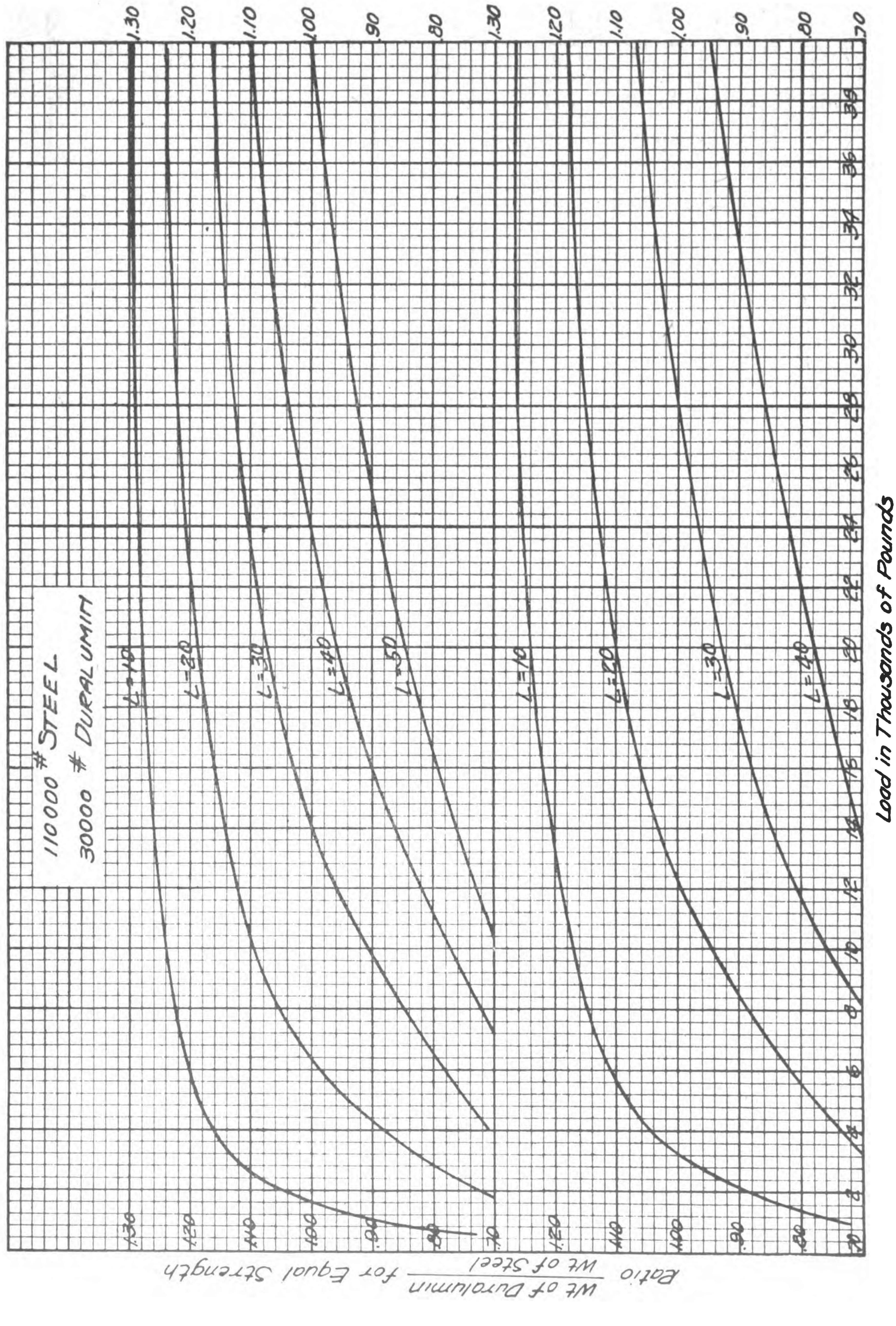
110000 # STEEL
30000 # DURALUMIN
L=10
L=20
L=30
L=40
L=50
L=10
L=20
L=30
L=40
Load in Thousands of Pounds
Ratio Wt of Duralumin / Wt of Steel for Equal Strength

FIG. 4.

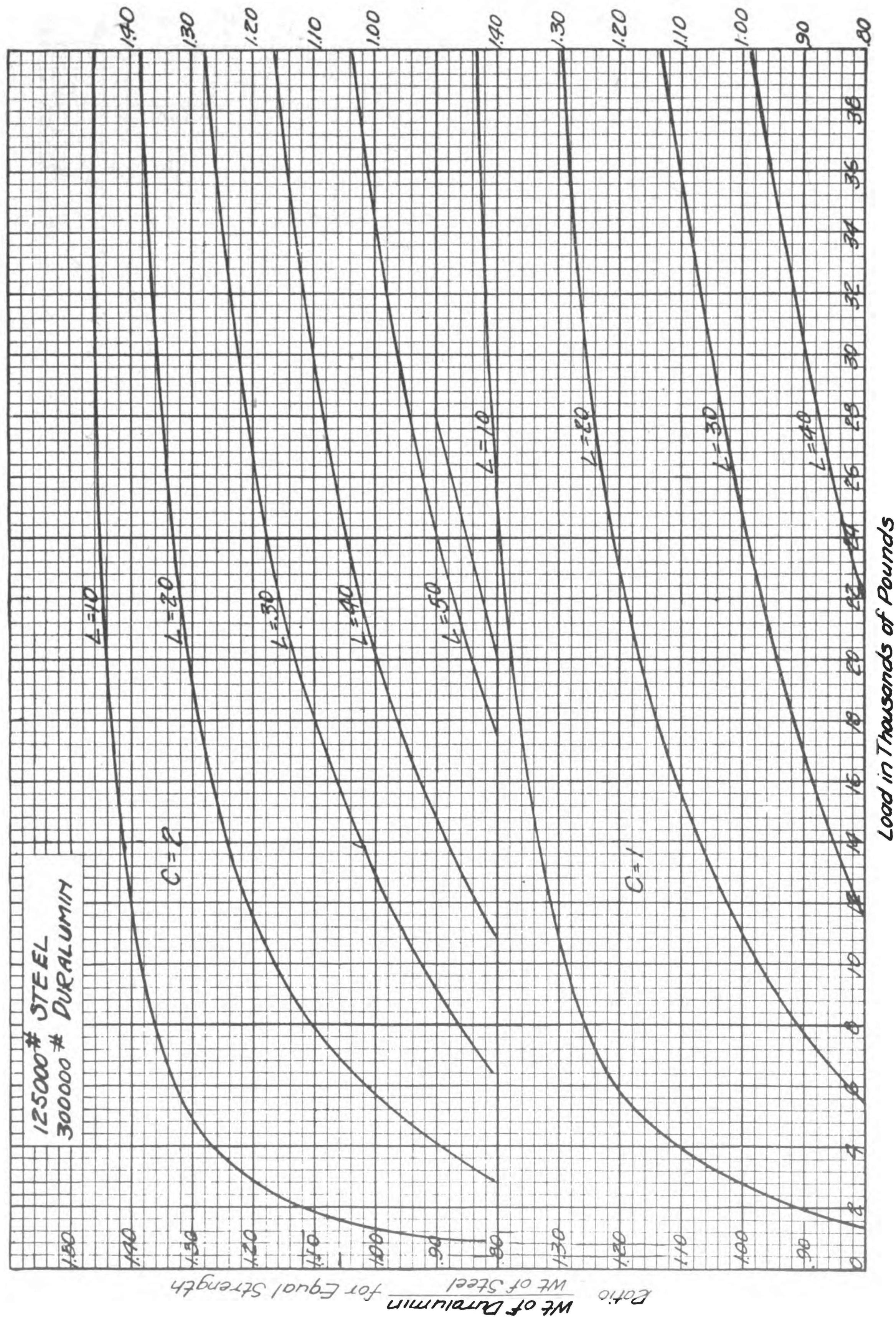
125000 # STEEL
300000 # DURALUMIN
C=2
C=1
L=10
L=20
L=30
L=40
L=50
Load in Thousands of Pounds
Ratio $\frac{\text{Wt of Duralumin}}{\text{Wt of Steel}}$ for Equal Strength
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
.80
.90
1.00
1.10
1.20
1.30
1.40
1.50

Fig. 5.

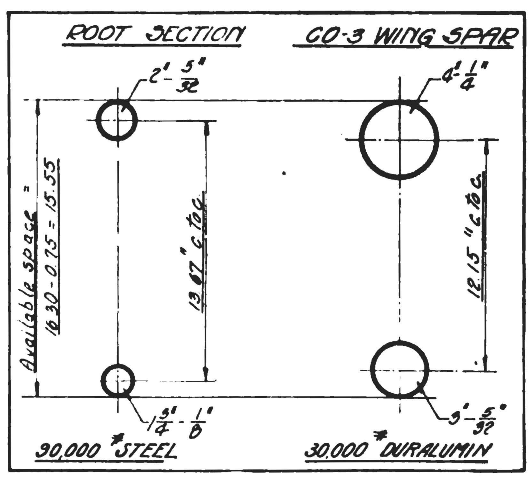
ROOT SECTION
CO-3 WING SPAR
2" - 5/32"
4" - 1/4"
Available space = 16.30 - 0.75 = 15.55
13.67" C to C
12.15" C to C
1 3/4" - 1/8"
3" - 5/32"
90,000 # STEEL
30,000 # DURALUMIN

FIG. 6.